ATMOSPHERIC POLLUTANT DEPOSITION MONITORING

NITROGEN AND PHOSPHORUS DEPOSITION AT THE MID-LAKE STATION OF LAKE TAHOE

DATA SUMMARY:

OCTOBER 1, 2021 – SEPTEMBER 30, 2022

SUBMITTED TO:

TAHOE REGIONAL PLANNING AGENCY

SUBMITTED BY:

TAHOE ENVIRONMENTAL RESEARCH CENTER

UNIVERSITY OF CALIFORNIA, DAVIS

BRANDON BERRY
AARON VANDERPOOL
SHOHEI WATANABE
GEOFF SCHLADOW

FEBRUARY 15, 2023

WY 2022 Mid-lake Atmospheric Deposition Data Summary

This document presents the data and a summary of results for atmospheric deposition monitoring of nitrogen (N) and phosphorus (P) at TERC's mid-lake atmospheric deposition station for the period October 1, 2021 – September 30, 2022. It includes results for water year (WY) 2022 N and P loads. Particulate data for PM2.5 from the CARB monitoring station in Tahoe City are also presented. A spreadsheet accompanying this document "WY2022_TERC_Mid-lake_AD_FINAL" presents summaries of the mid-lake atmospheric deposition since July, 2013, along with QA/QC data, estimated WY loading for N and P, and loading rate information.

This report forms part of Deliverable 2 under Contract #20C00008 between the TRPA and the Regents of the University of California.

Sampling Methods

Samples of atmospheric deposition to the lake were collected from mid-lake buoy TB1, in the north central portion of the lake (coordinates 39.1550000°N, 120.0041670°W). The collector consists of a modified 3 ½ gallon HDPE plastic bucket with reduced (6 inch) side-wall height, with 2.75 inch high removable plastic baffles inside (to dampen splash from the bucket). The bucket is partially filled with 4 liters of deionized water and placed on the buoy for a sampling period of 1-2 weeks. The collector at mid-lake is considered a "bulk collector" since it collects both wet deposition (from precipitation) and dry deposition (from settling particles, as well as atmospheric gases under non-precipitation periods).

A cleaned collector is deployed on the buoy at 10-14 day intervals. At the same time, the previously deployed collector is retrieved. Both before and after deployment, the collector is wrapped in a clean plastic bag to avoid inadvertent contamination. The collector is transported to the lab facility at TERC and stored in the cold room (4°C) until processing.

Once at the lab, the samples are processes within 48 hours. Final water volume is measured to allow the concentrations of NO_3-N, NH_4-N, TKN, SRP and TP to be determined. If the collector is dry after the deployment period, deionized water is added to the collector to facilitate analysis. The analytical methods used are the same as those used for lake water analysis and are fully described in the *Laboratory Procedure, Field Protocol and Quality Assurance Manual* (Liston et al., 2013).

The loading (g/ha) and loading rate (g/ha/day) for sample nutrients are calculated based on the bucket surface area and the duration of the deployment, with the implicit assumption that this one sample is representative of a broader area. Samples with contamination or otherwise compromised data were deleted from the dataset (see QA/QC section). Contamination most commonly occurred due to bird activity. Total Water Year (WY) load (g/ha/yr) at mid-lake was estimated from the average loading for uncensored data. Dissolved inorganic nitrogen (DIN) (NO_3-N + NH_4-N) loading and total nitrogen (TN) (NO_3-N + TKN) loading were also determined.

For QA/QC samples, source deionized water samples, field blanks, and equipment blanks were analyzed. The source deionized water consisted of ultra-pure water collected from TERC's Milli-

Q System. The field blank consisted of 4 liters of ultra-pure water added to a cleaned plastic bulk-deposition bucket, the bucket was enclosed in a plastic bag and held overnight in a cold room, then processed as a typical atmospheric deposition sample. The equipment blank consisted of 4 liters of ultra-pure water added to the carboy which is used to transport DI water. The equipment blank is held overnight in a cold room, then processed as a typical atmospheric deposition sample.

Data Summarized in Spreadsheet: "2022 TERC Mid-lake AD Final"

Data are summarized in the spreadsheet "WY2022_TERC_Mid-lake_AD_FINAL". A total of 33 new mid-lake atmospheric deposition samples were collected during October 1, 2021 – September 30, 2022. The data for these samples are summarized in Table A along with data collected for samples back to June 27, 2013. Table B presents the data for 3 source blanks, 3 field blanks, 3 equipment blanks, QA/QC samples collected during the period along with all QA/QC values back through 2013. Table C presents a summary of estimated WY2022 DIN, TN, SRP and TP atmospheric deposition in loads per year (grams/hectare/year) along with the historical WY values. Table D in the spreadsheet presents a summary of atmospheric deposition as average daily loading rates of DIN, TN, SRP, TP (grams/hectare/day) for WY 2022 along with the historical values.

Project Quality Assurance

Standardized QA/QC practices for chemical analyses were followed as specified in the TERC QA/QC manual (Liston et al., 2013). For QA/QC in atmospheric deposition monitoring, a primary objective was to check for contamination associated with field monitoring equipment. Nutrient levels in field blanks and equipment blanks were compared with a source deionized water (ultra-pure Milli-Q deionized water) and also compared with the Method Detection Levels (MDLs) to check for contamination.

Three source blank, three bulk-deposition bucket field blanks, and three equipment blank were collected during the year. The first two sets of blanks in February and April showed very low or no contamination with N and P (Table B in the spreadsheet). The last set of blanks on September 9, 2022 displayed elevated results for NO_3 and TP. These results are likely attributed to contamination in sample bottles. All equipment was thoroughly washed after blank samples to ensure minimal contamination of field samples.

The atmospheric deposition data were reviewed and data subjected to quality control prior to calculation of loads. Atmospheric deposition samples may be contaminated with bugs, bird droppings, lake water splash or material from the buoy surfaces. Samples may be lost due to sample splash out of the bucket during very rough lake conditions. Samples may also sit for prolonged periods when researchers are unable to get to the buoy due to extended periods of adverse lake conditions. When the buckets go dry, the deposition collection efficiency can change. Values censored from the data included mid-lake samples which: (1) had potential contamination due to insects and debris, (2) potential contamination during transport, and (3) potential contamination due to bird droppings in sample. In WY 2022, three samples were censored. The censored data in WY 2022 was during November 16 - 30, 2021, April 7 -25, 2022, and May 24 – June 6, 2022. The corresponding samples were during the fall and early summer season, with no wildfire activity during those timeframes. Due to the seasonality of the censored data, it is likely that N and P concentrations were not outlying data at the time, leading to little bias in the loading rates for WY 2022.

WY 2022 Wildfire Smoke

Atmospheric deposition data during WY 2022 was impacted by California wildfires and associated smoke. Although less severe than the previous year's wildfire impacts, the more intense and longer wildfire season continues to have a large impact on atmospheric deposition at Lake Tahoe. The trend continues with increases in N and P deposition in the Lake Tahoe Basin being directly correlated with wildfire activity. WY 2022 realized impacts from wildfire smoke due to the Washburn, Oak, and Mosquito Fires burning in the Sierra. The Washburn Fire lasted from July 7 – August 4, 2022 and was relatively small (4,886 acres) with limited impacts on Lake Tahoe. The Oak Fire continued from July 22 through August 10, 2022, burning 19,244 acres near Yosemite. The Mosquito Fire continued from September 6 through October 27, 2022, burning 76,788 acres in Placer County near Foresthill, CA (Cal Fire. *2022 Fire Season*). The Lake Tahoe Basin experienced periods of smoke related to the Washburn and Oak fires, and extended periods of heavy smoke during the Mosquito Fire, all contributing to N and P loading rates for WY 2022.

Monitoring Results:

Dissolved Inorganic Nitrogen (DIN) Loading

Figure 1 shows the patterns for DIN loading rate (g/ha/d) from July 2013 through September 2022. The vertical axis, DIN Loading (g ha^{-1} day^{-1}), is displayed on two axes to compensate for the dramatic increase in loading over the past two years. In WY 2022, DIN loading was estimated to be 2644 g ha^{-1} or 7.24 g/ha/d (Tables C and D in spreadsheet data summary). DIN loading in WY 2022 decreased compared to loading rates in WY 2021 (4459 g/ha/yr or 12.22 g/ha/d). Despite decreasing from WY 2021's unprecedented DIN loading rates, WY 2022 includes some of the largest rates since the inception of the atmospheric monitoring program in 1994.

Major sources of atmospheric nitrogen pollutants in the basin have been identified in other research studies. Historically, motor vehicle emissions are thought to be the largest contributor to atmospheric nitrogen pollutants in the basin (Gertler et al., 2006; CARB, 2006 referenced in NDEP, 2011). However, the continued increase in loading rates in recent years, including WY 2022, are likely associated with increased wildfires in California, especially those within close proximity to the Lake Tahoe Basin. Wildfire smoke from these fires inundated the Lake Tahoe Basin for periods during 2022. Extreme periods of wildfire smoke in the Lake Tahoe Basin are likely the cause of the substantial increase in DIN loading rates. It is noteworthy that during peak periods of smoke activity in the basin, tourism and subsequent vehicle emission remain at low levels.

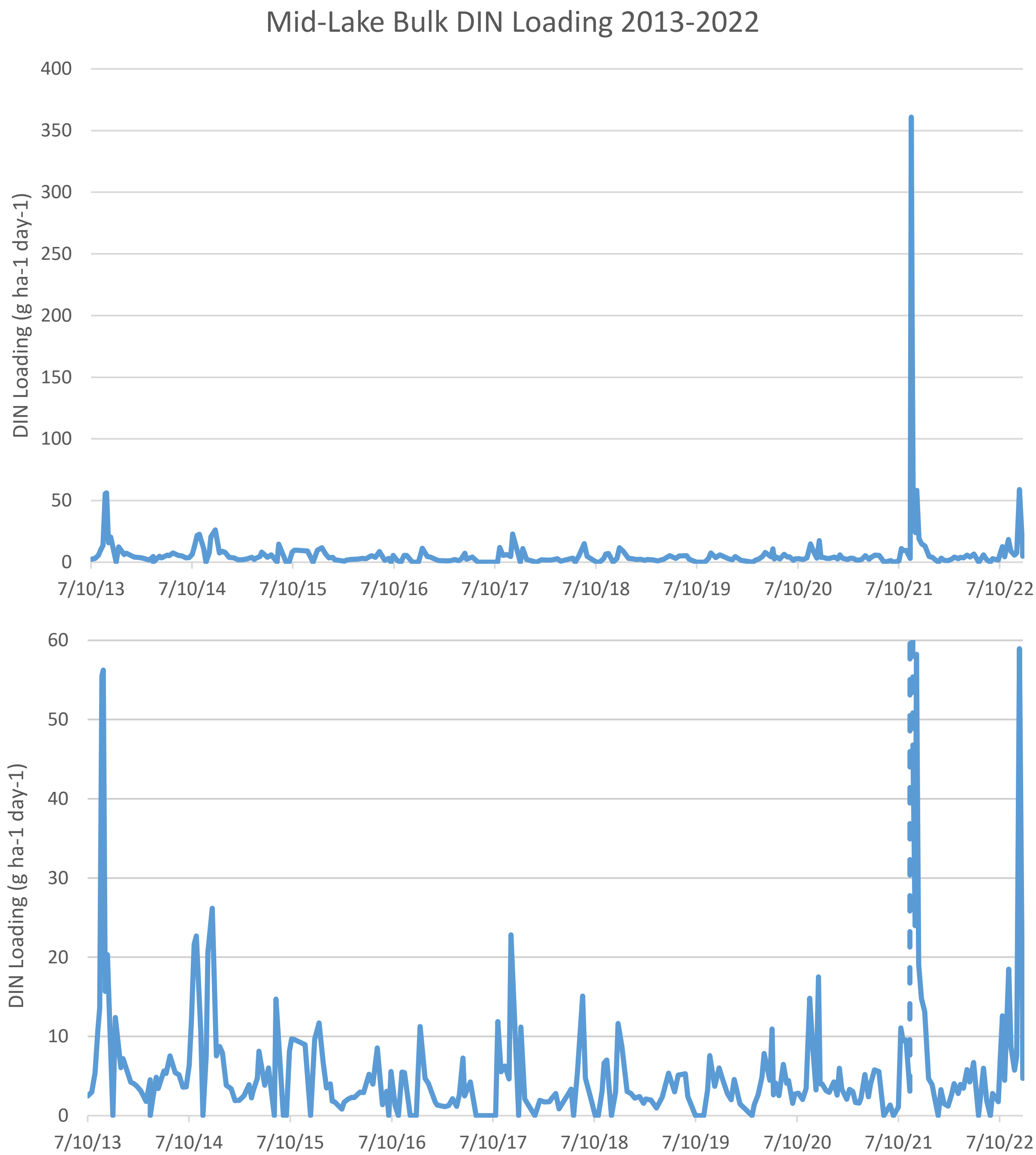

Figure 1. Loading rate of DIN (NO_3-N + NH_4-N) in bulk atmospheric deposition at mid-lake station during July 2013 – September 2022. Two different scales are used to highlight the exception values in recent years (upper figure) and to illustrate the seasonality (lower figure) with higher deposition rates in summer.

Total Nitrogen (TN) Loading

Figure 2 shows the patterns for TN loading rate (g/ha/d) from July, 2013 through September, 2022. The vertical axis, TN Loading (g ha^{-1} day^{-1}), is displayed on two axes to compensate for the dramatic increase in loading during recent years. In WY 2022, TN loading was estimated to be

3228 g ha^{-1} or 8.84 g/ha/d (Tables C and D in spreadsheet data summary). TN loading in WY 2022 decreased compared to loading rates in WY 2021 (5917 g/ha/yr or 16.21 g/ha/d). WY 2022 included elevated TN loading rates compared to historical data, but contained roughly half the loading rates of WY 2021.

Similar to DIN, TN levels are impacted by N from motor vehicle emissions, particulate-associated N (which may include such sources as inorganic and organic N associated with wind-blown dust, pollen, and wind-blown organic matter from forests), thunderstorms and smoke inputs. Past data indicates that spikes in TN loading are associated with wildfire smoke affecting the Lake Tahoe Basin. The summer of 2021 had a dramatic peak in TN directly correlated with wildfire smoke reaching the Tahoe basin. Elevated loading of TN in the WY 2022 is also likely due to impacts from wildfire smoke. The recent increase in TN values can be attributed to the severity and close proximity of the wildfires. In wildfire smoke, small particulate matter (PM2.5) is one of the principal air pollutants and a good indicator of smoke related air quality. There is a distinct visual correlation between increases in TN loading and increases in PM2.5 throughout WY 2022 (Figure 3). There is also a clear statistical correlation between TN and PM2.5 for WY 2022 with an $R^2 = 0.85$. The PM2.5 concentrations displayed in Figure 3 are the average PM2.5 concentration during the atmospheric deposition sample period. Deposition deployment periods with the highest TN loading rates also represent the highest PM2.5 concentrations (September 9 - 19, 2022). Daily average PM2.5 concentrations were recorded at the Tahoe City site located at 221 Fairway Drive (CARB. Air Quality and Meteorological Information). Wildfire smoke impacts in the Lake Tahoe Basin are the probable source of elevated levels of TN loading during the WY 2022.

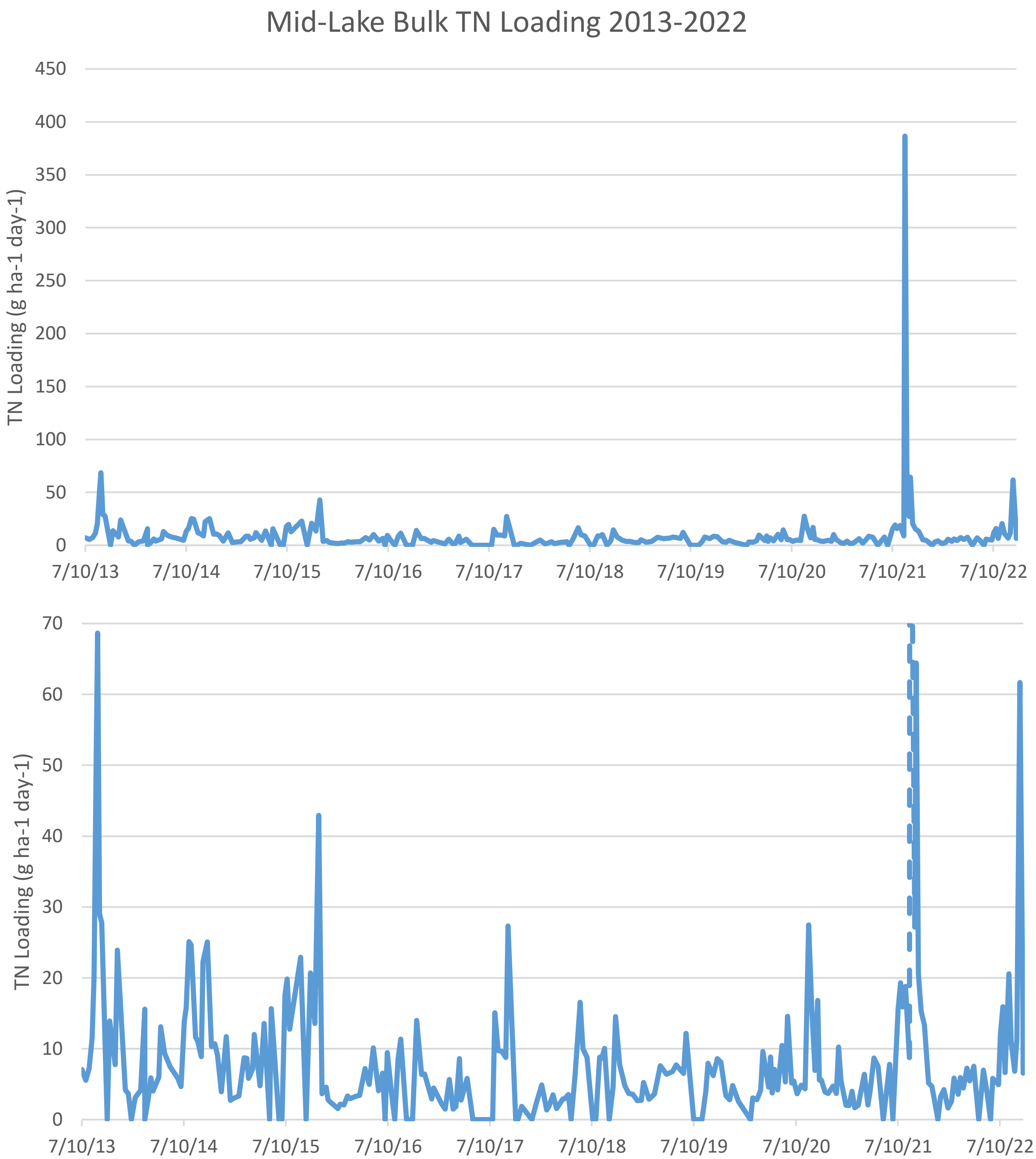

Figure 2. Loading rate of TN (NO_3-N + TKN) in bulk atmospheric deposition at mid-lake station during July 2013 – September 2022.

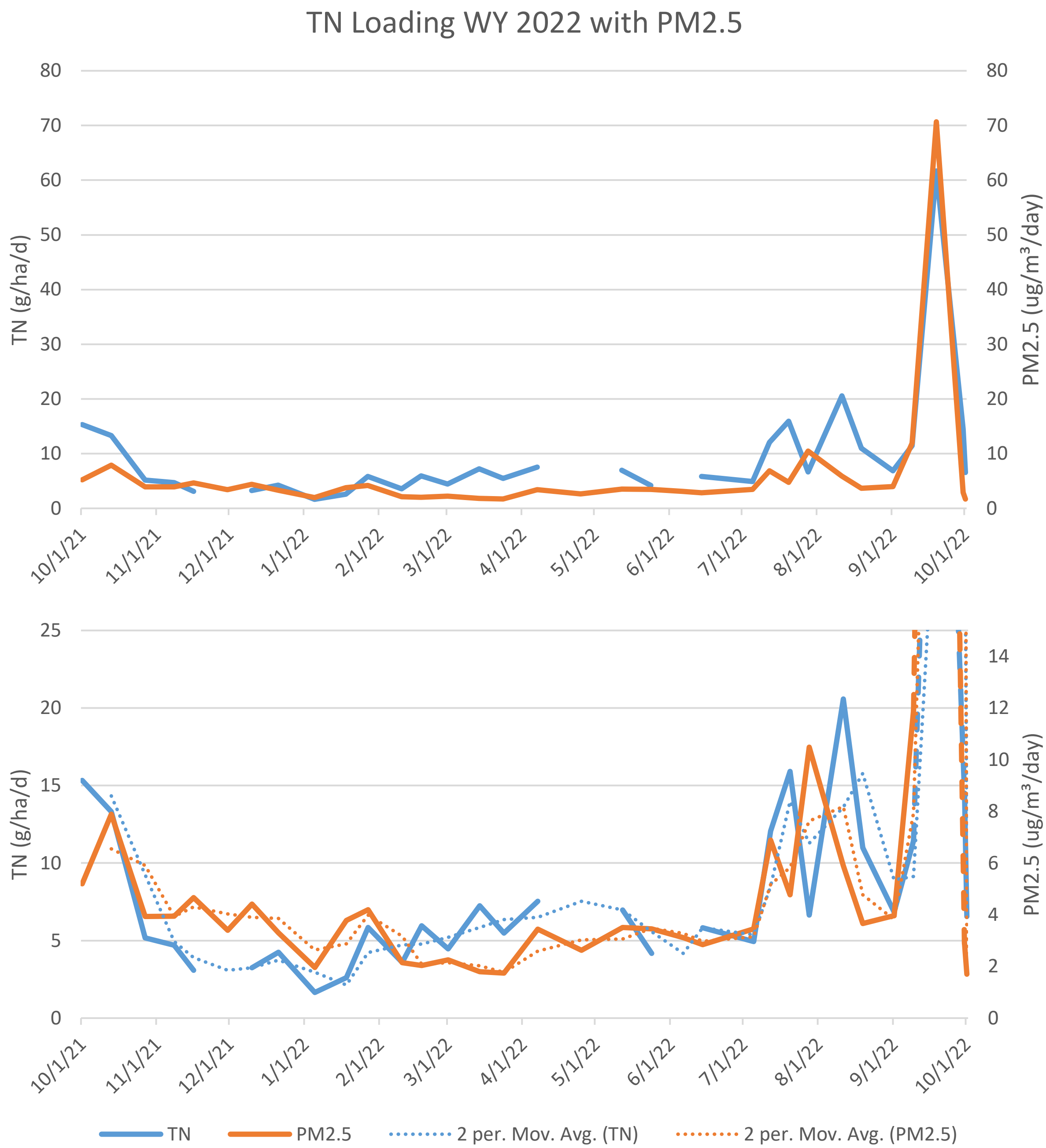

Figure 3. Loading rate of TN (NO_3-N + TKN) at mid-lake station for WY 2022 compared to average daily PM2.5 concentrations with moving average trendline.

Soluble Reactive Phosphorus (SRP) Loading

Figure 4 shows the patterns for SRP loading rate (g/ha/d) from July 2013 through September 2022. The vertical axis, SRP Loading (g ha^{-1} day^{-1}), is displayed on two axes to compensate for the dramatic increase in loading during recent years. In WY 2022, SRP loading in bulk atmospheric deposition at mid-lake was an estimated 78.28 g/ha/yr or 0.21 g/ha/d (Tables C and D in spreadsheet data summary). Assuming the same deposition rate over the entire

49,500 ha. surface area of the lake, this would be equivalent to 3.9 metric tons/year. By comparison the long-term average SRP load from the Upper Truckee River is 0.49 metric tons/year. SRP loading in WY 2022 decreased compared to loading rates in WY 2021 (175.73 g/ha/yr or 0.48 g/ha/d). SRP loading rates in WY 2022 dropped significantly from the extreme values in WY 2021, but remain larger than loading rates in WY 2020.

WY 2022 exhibited the second largest SRP loading rate on record. Previous years with high SRP loading are correlated to wildfire smoke in the Tahoe basin. WY 2021 contained loading rates of 175.73 g/ha/yr which can be attributed to the numerous wildfires in close proximity to Lake Tahoe during summer 2021. Loading rates in 2013 were 30.77 g/ha/yr as a result of the Rim Fire near Yosemite. Smoke in the basin from the American River Complex fire in 2008 contributed to an SRP loading of 52.40 g/ha/yr. However, SRP inputs during WY 2022 are only exceeded by those during WY 2021. The substantial increase in SRP loading within the Tahoe basin can be attributed to the increase in wildfires and their immediate vicinity to Lake Tahoe.

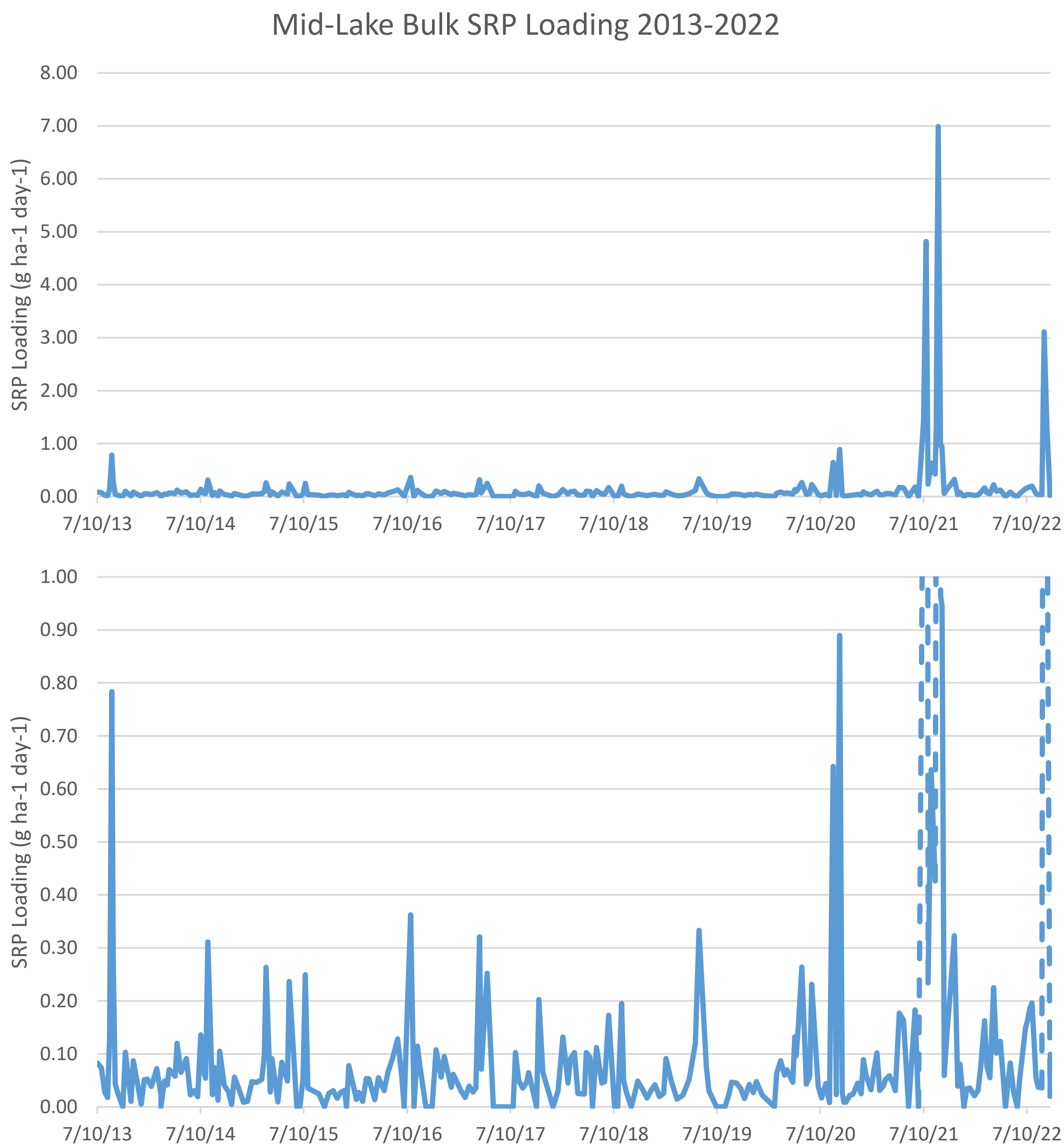

Figure 4. Loading rate of SRP in bulk atmospheric deposition at mid-lake station during July 2013 - September 2022.

Total Phosphorus (TP) Loading

Figure 5 shows the patterns for TP loading rate from July, 2013 through September 2022. The vertical axis, TP Loading (g ha^{-1} day^{-1}), is displayed on two axes to compensate for the dramatic increase in loading during recent years. In WY 2022, TP loading in bulk atmospheric deposition at mid-lake was an estimated 206.84 g/ha/yr or 0.57 g/ha/d (Tables C and D in spreadsheet data summary). Assuming the same deposition rate over the entire 49,500 ha. surface area of the lake, this would be equivalent to 10.2 metric tons/year. By comparison the long-term average Total Phosphorus load from the Upper Truckee River is 3.2 metric tons/year. TP loading in WY 2022 decreased compared to loading rates in WY 2021 (333.60 g/ha/yr or 0.91 g/ha/d). Both TP daily loading rates and yearly load were the second highest levels on record back through 1994.

A variety of factors impact levels of TP in atmospheric deposition samples in the basin. Gertler et al. (2006) indicate the primary factors are the mobilization of local sources from roadway sanding and salting in the winter, and from local soils in the summer and vehicle exhaust. Observations of material deposited in buckets indicates that wind-blown dust, pollen, wind-blown organic matter from the forests may also be potential sources of TP, along with TP contributed with smoke and ash. More recently, wildfire smoke and ash continue to play a larger role in P deposition in the Tahoe Basin. Significant increases in TP loading in the WY 2021 and 2022 can be attributed to extensive wildfire smoke in the basin. Previous years with increases in TP loading were also affected by wildfire smoke. It is noteworthy that during peak periods of smoke activity in the basin, tourism and subsequent vehicle emission remain at low levels.

The data for WY 2022 contains the second highest yearly TP load on record for the monitoring program, which was set last year in WY 2021. Similar to TN, the visual correlation between significant TP increases in the late summer of WY 2022 are directly related to increases in PM2.5 within the basin (Figure 6). The statistical correlation between TP and PM2.5 for WY 2022 is $R^2 = 0.08$. It is apparent that the wildfires contributed to an increase in TP loading in the Tahoe basin during WY 2022. Wildfires are establishing themselves as the primary source of TP deposition in the Tahoe Basin.

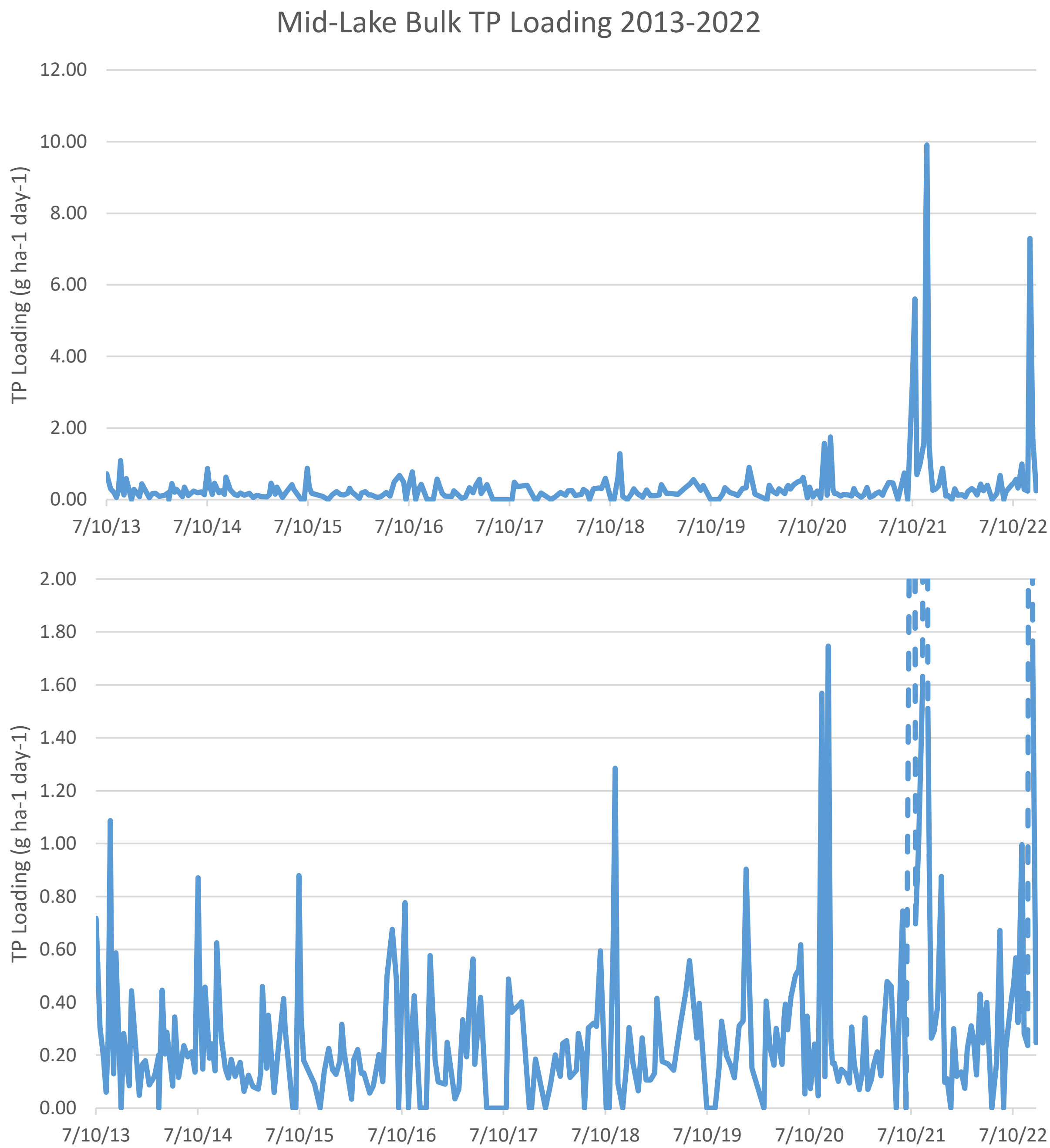

Figure 5. Loading rate of TP in bulk atmospheric deposition at mid-lake station during July 2013 – September 2022.

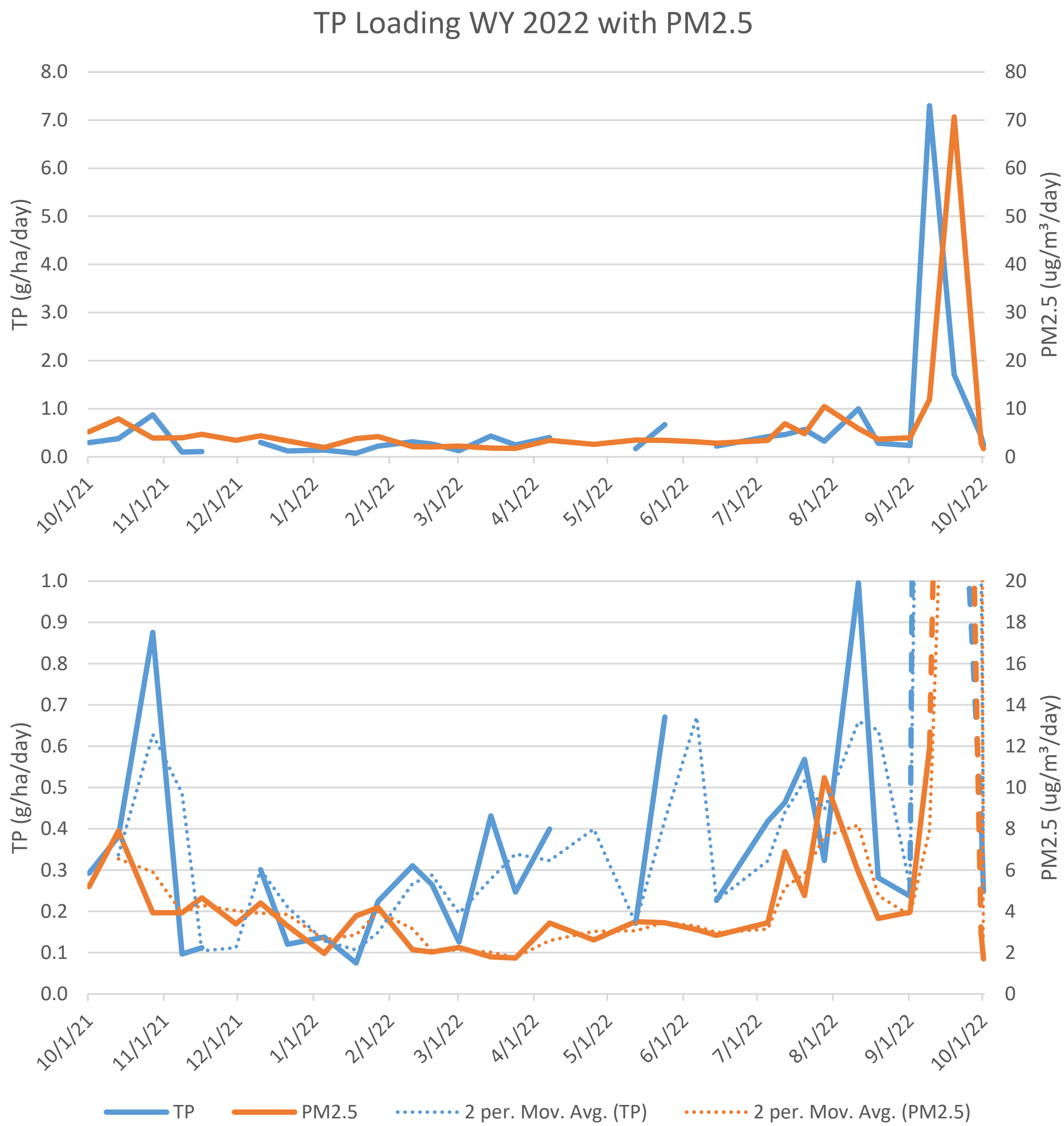

Figure 6. Loading rate of TP at mid-lake station for WY 2022 compared to average daily PM2.5 concentrations with moving average trendline.

Acknowledgements

We acknowledge the assistance provided in the field and the laboratory by Brant Allen, Katie Senft, Erik Young, Anne Liston, Steven Sesma and Helen Fillmore.

References

Cal Fire. *2022 Fire Season.* https://www.fire.ca.gov/incidents/2022/.

CARB (California Air Resources Board). 2006. Lake Tahoe Atmospheric Deposition Study (LTADS). Final Report – August, 2006. Atmospheric Processes Research Section, California EPA, Sacramento, CA.

CARB (California Air Resources Board). Air Quality and Meteorological Information. Tahoe City – 221 Fairway Dr Site. 4 Jan. 2023: https://www.arb.ca.gov/aqmis2/.

Gertler, A.W., Bytnerowicz, A., Cahill, T.A., Arbaugh, M., Cliff, S., Kahyaoglu-Koracin, J., Tarnay, L., Alonso, R. and W. Fraczek. 2006. Local air pollutants threaten Lake Tahoe's clarity. California Agriculture 60(2):53-58.

Liston, A., T. Hammell, V. Edirveerasingam, B. Allen, S. Hackley, J. Reuter and G. Schladow. 2013 Updated June 24, 2014). *Laboratory Procedure, Field Protocol and Quality Assurance Manual*, Tahoe Environmental Research Center, University of California, Davis. 158 p.

NDEP (Nevada Division of Environmental Protection). 2011. Final Lake Tahoe Total Maximum Daily Load. NDEP, Carson City, NV.